PRELIMINARY EVALUATION OF SEVERAL LATERAL CONTROL CONFIGURATIONS FOR SAILWINGS

By

Captain David W. Morrill, USMC

VET. TES MEN NOV. TA- TUM

DEI SUB NUMINE VIGET

PRINCETON UNIVERSITY

TMENT OF AERONAUTICAL ENGINEERING

PRELIMINARY EVALUATION OF SEVERAL LATERAL CONTROL CONFIGURATIONS FOR SAILWINGS

By

Captain David W. Morrill, USMC

//

Submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering from Princeton University, 1962.

ACKNOWLEDGEMENT

The author wishes to thank Mr. T. E. Sweeney for the opportunity to participate in the program of Sailwing research under his direction and for the many helpful suggestions which he made in guiding this investigation to its successful conclusion.

TABLE OF CONTENTS

	Page
Acknowledgement	i
List of Figures	iii
Summary	iv
Introduction	1
Test Vehicles	2
Lateral Control Configurations	4
Tests	7
Discussion	9
Conclusions and Recommendations	21
References	22
Figures	

INTRODUCTION

The sailwing concept, developed at Princeton by Mr. T. E. Sweeney, was initially disclosed in Ref. 1. The results of preliminary research, which included wind tunnel and free flight model tests, are reported in Ref. 2. The promising nature of these results led to the construction of a full-scale, one-man sailwing glider. The initial tests of this machine were undertaken with the primary objective of devising a lateral control system which would not only meet the specific requirements of the glider, but would possibly be adaptable to other sailwing applications as well.

The basic sailwing structure consists of a drooped D-spar leading edge, a fixed root section, a reinforced tip, and a tensioned braided wire trailing edge. Over this a flexible fabric is sewn to the trailing edge cable and firmly attached to the contours of the tip and root sections.

The unique structural simplicity of this design does not lend itself readily to conventional aileron configurations due to the lack of rigid attachment points along the trailing edge. In the design of a suitable control system the additional restriction was imposed that the system should require no additional structure which might compromise the simplicity and flexibility of the wing or interfere with its foldability.

In the course of this investigation four different lateral control systems were evaluated:

LIST OF FIGURES

1. General View of Sailwing Glider

2. Aspect Ratio 11 Sailwing Geometry

3. Aspect Ratio 7 Sailwing Installation

4. Detail of Aspect Ratio 7 Sailwing Mounting

5. Aspect Ratio 7 Sailwing Geometry

6. Trailing Edge Cable Deflections During Tip Warping of Aspect Ratio 11 Sailwing

7. Trailing Edge Bridle Configuration

8. Spanwise Views of Bridle Influence on Trailing Edge Cable at 25 mph.

9. Influence of Flap-type Aileron Deflection on Camber Distribution of Aspect Ratio 7 Sailwing at 25 mph.

10. Influence of Flap-type Aileron Deflection on Trailing Edge Cable of Aspect Ratio 7 Sailwing at 30 mph.

11. Ballooning Effect Due to Leading Edge Spoilers on Aspect Ratio 11 Sailwing

12. Rolling Moment Characteristics of Three 90° Spoilers on Aspect Ratio 7 Sailwing

13. Rolling Moment Characteristics of Flap-type Ailerons, Aspect Ratio 7 Sailwing

14. Rolling Moments Due to Independent Aileron Deflections, Aspect Ratio 7 Sailwing

15. Effect of Angle of Attack on $\frac{pb}{2V}/\delta a$, Aspect Ration 7 and 11 Sailwings

SUMMARY

A preliminary evaluation of several lateral control configurations for sailwings was conducted at Princeton during the winter and spring of 1961-62. The primary objective was to devise a suitable system for the aspect ratio 11, piloted sailwing glider which would lend itself to other sailwing applications as well.

The designs considered included wing tip warping, leading edge spoilers, partial trailing edge deflection, and a modified flap-type aileron configuration. The spoilers were found to be ineffective in producing rolling moments at deflections up to 60 degrees due to a ballooning effect of the upper sail. The tip warping and partial trailing edge deflection designs were characterized by unacceptably high static control forces and low control effectiveness. The modified flap-type aileron configuration was evaluated using an aspect ratio 7 test wing and was found to be satisfactory in producing rolling moments over the intended performance range of the sailwing glider. It was recommended for installation on the glider.

1. Wing tip warping.
2. A bridle arrangement to deflect the trailing edge cable downward and forward, thereby increasing the camber over a part of the semispan.
3. Leading edge spoilers.
4. Modified flap-type ailerons.

The evaluation of each system was by no means complete. For example, the first two designs were exploratory in nature. They were intended primarily to reveal the order of magnitude of the control forces to be encountered in deflecting a major portion of the trailing edge cable against its own tension. The most extensive tests were made with the final design, since it showed the greatest promise of providing satisfactory lateral control with acceptable stick forces.

TEST VEHICLES

Piloted Sailwing Glider

A general view of the sailwing glider is shown in Fig. 1, and the wing geometry is detailed in Fig. 2. The pertinent specifications of the glider are as follows:

Span:	31 ft.	Wing Area:	87 $ft.^2$
Length:	19 ft.	Aspect Ratio:	11
Height:	6.75 ft.	Taper Ratio:	44

Weight (with pilot): 480 lbs.

The wing covering (sail) is 3.8 oz. Dacron selected for its resistance to stretch and lack of porosity. The sail was made with alternating colored strips running chordwise to facilitate investigation of surface deformations during testing. The leading edge D-spar is drooped to provide a smoother camber of the lower surface under flight loads, and the spar is hinged at the root section so that the wing can be folded back along the fuselage.

Test Wing

To investigate the effectiveness of the final design more fully a smaller scale sailwing was constructed and mounted on a jeep as shown in Fig. 4. This wing has a three-inch tubular leading edge resulting in a symmetrical section at all stations at $\alpha = 0^{\circ}$. A reinforced tubular section at the wing centerline supports two lever arms of 3/8" steel rod. The ends of these levers ride in sleeve bearings in the centerline structure so that they may be rotated up or down out of the plane of the wing. The trailing edge cables run from the aft end of the arms to the trailing edges of the fixed wing tips. The details of this arrangement are shown in Fig. 4 and 5. The sail is made of untreated cotton aircraft fabric which is sewn to the trailing edge cables and to the movable arms. The geometric characteristics of the wing are:

Span:	10.2 ft.	Aspect ratio:	7
Area:	14.9 ft.	Taper ratio:	.5
Mean Chord:	1.4 ft.		

The wing mounting places the wing well above and ahead of the jeep to reduce interference effects and allows the wing to rotate laterally about its hinge line when unrestrained. This mounting is quite rigid and provides for adjustment of wing angle of attack over a range of approximately ± 60 degrees as shown in Fig. 4.

The instrumentation consisted solely of a pitot static probe mounted on the hood of the jeep with the tip projecting slightly ahead of the wing and connected to an airspeed indicator on the instrument panel.

LATERAL CONTROL CONFIGURATIONS

General

The first three control configurations considered were installed on the sailwing glider, while all testing of the final design was done with the test wing. At the time of this writing modification of the glider to the final configuration had not been accomplished.

Tip Warping

Each wing tip section was hinged at .30 c so that the after portion could be deflected up or down approximately 30° carrying the trailing edge cable with it, and thereby effectively increasing or decreasing the angle of attack and camber of a large part of the semispan. The hinged tip sections were connected to the control stick by cables which passed spanwise just behind the D-spar inside the wing.

aft edge of the D-spar on the upper surface of each wing. The inboard edge of each spoiler was located at .62 $^{b}/_{2}$, and both spoilers had 65 evenly spaced, one inch diameter holes representing a flat plate area reduction of 51 square inches. Maximum spoiler deflection was 60 degrees of elevation from the wing surface.

Spoilers were also installed on the jeep-mounted sailwing for a brief series of tests. Three rectangular, flat plate spoilers were used; all were 36 inches long with chords of one, two and three inches. They were mounted on the upper surface of the tubular leading edge spar at a fixed deflection of 90° to the zero lift line of the wing and extended from .35 $^{b}/_{2}$ to .95 $^{b}/_{2}$.

Modified Flap-type Ailerons

This configuration was incorporated in the jeep-mounted test wing previously described. The flapped area of the semispan was roughly triangular, such that the wing chord ahead of the aileron was approximately constant as illustrated in Fig. 5. Maximum deflection was $\pm 35^{\circ}$, and a simple locking device on each aileron held it at any desired deflection within this range. No control cables were used, each aileron being set and locked manually.

To facilitate fabrication the hinge lines of the aileron arms were offset one inch at the wing centerline resulting in a slightly larger flapped area on the left wing than the right. The left wing area was 1.6 square feet and the right was 1.5 square feet. The mean geometric aileron

Fig. 2 illustrates the area of the wing affected by deflection of the tip, and Fig. 6 shows the approximate positions of the trailing edge cable at maximum deflections. It is readily seen from Fig. 6 that the degree of change of angle of attack is a function of position along the semispan. Control was in the positive sense, right stick deflection producing a positive rolling moment.

<u>Trailing Edge Bridle</u>

In this configuration 3 braided wire cables were attached to the wing trailing edge cable at points .64, .50 and .36 of the semispan as shown in Fig. 7 (a). These cables were joined at a common point to a control cable which passed through two pulleys on the wing strut and then directly to the control arm on the stick. Lateral deflection of the stick increases the tension in one control cable while allowing the other to go slack, thereby deflecting one trailing edge cable downward and forward as the cable on the other wing is freed to deflect upward to its normal loaded position. Fig. 8 shows the positions of one trailing edge cable with neutral stick and with full left and right deflections. When the wing is loaded in flight the maximum change in angle of attack is obtained at $.5\,{}^{b}/_{2}$ and was measured to be approximately $+10^{\circ}$ and -3^{0}. Both the positive and negative increments in angle of attack approach zero along the semispan toward the tip and the root from the $.5\,{}^{b}/_{2}$ location, as shown in Fig. 7 (b).

<u>Leading Edge Spoilers</u>

A hinged spoiler, 48" long with a 6" chord, was attached along the

aft edge of the D-spar on the upper surface of each wing. The inboard edge of each spoiler was located at .62 $^{b}/_{2}$, and both spoilers had 65 evenly spaced, one inch diameter holes representing a flat plate area reduction of 51 square inches. Maximum spoiler deflection was 60 degrees of elevation from the wing surface.

Spoilers were also installed on the jeep-mounted sailwing for a brief series of tests. Three rectangular, flat plate spoilers were used; all were 36 inches long with chords of one, two and three inches. They were mounted on the upper surface of the tubular leading edge spar at a fixed deflection of 90° to the zero lift line of the wing and extended from .35 $^{b}/_{2}$ to .95 $^{b}/_{2}$.

Modified Flap-type Ailerons

This configuration was incorporated in the jeep-mounted test wing previously described. The flapped area of the semispan was roughly triangular, such that the wing chord ahead of the aileron was approximately constant as illustrated in Fig. 5. Maximum deflection was $\pm 35^{\circ}$, and a simple locking device on each aileron held it at any desired deflection within this range. No control cables were used, each aileron being set and locked manually.

To facilitate fabrication the hinge lines of the aileron arms were offset one inch at the wing centerline resulting in a slightly larger flapped area on the left wing than the right. The left wing area was 1.6 square feet and the right was 1.5 square feet. The mean geometric aileron

chord was 4.7 inches while the wing chord ahead of the aileron was 13 inches.

Typical variations in camber and trailing edge cable deformation of the test wing with aileron deflection are shown in the spanwise and chordwise photographs of Fig. 9 and 10.

TESTS

As mentioned previously, tests of the control configurations which were installed on the sailwing glider were qualitative in nature. These consisted of towing the glider with an automobile on the 3000 foot, hard surfaced runway at Forrestal airfield. The glider was towed until air-borne, then released by the pilot using the cockpit cable release, and flown to touchdown. Sixteen flights were made at heights of only a few feet for durations up to ten seconds. During these flights the effect of lateral stick deflections on wing attitude were observed by attempting to make shallow banks or, in most cases, to maintain a wings level attitude during small gust disturbances. In addition, numerous ground run tow tests were made for visual and photographic observation of the deformations of the sail and trailing edge cable in the different configurations.

Tests of the jeep-mounted sailwing were conducted to determine the rolling moment coefficient generated over a range of angles of attack and aileron deflections. During these tests a known weight was suspended from the wing leading edge at a point 4.8′ from the center station. The

wing was restrained from an excessive wing-down attitude, due to the added weight, by a line from the jeep to the opposite wing tip. With the ailerons adjusted to generate a rolling moment opposing the weight moment the jeep was slowly accelerated. The airspeed at which the wing could be maintained in a level attitude was recorded. Under relatively calm wind conditions it was possible to maintain a level wing attitude at essentially constant airspeed, but this equilibrium was quite sensitive to small gusts and crosswinds. Consequently, much of the testing was done in the early morning hours when optimum wind conditions existed.

By switching the weight to the opposite wing tip and reversing the aileron deflections during preliminary testing it was found that there was no appreciable wing assymmetry effect on rolling moments.

Four series of tests were completed. In the first, the ailerons were deflected equally - one up and the other down - from five to 35 degrees in five degree increments at anglesof attack from zero through 25 degrees. The second series was run at α = 10 and 20 degrees. One aileron was fixed in the neutral position, and the other was deflected through the complete range from -35 to $+35$ degrees in five degree increments to isolate the effects of positive and negative deflections.

The next series was made with the three leading edge spoilers. With the ailerons locked at zero deflection each spoiler was tested at α = 0, 5, 10,......through 25 degrees. For the final tests the sail was treated with one coat of a one-to-one mixture of clear dope and thinner to

reduce the porosity. Then the first series of tests was partially repeated at α = 10 and 20 degrees only to determine the effect of decreased porosity on the rolling moments.

Each test run, with the exception of the spoiler series, was repeated with the weight switched to the opposite tip and the aileron deflections reversed to minimize possible crosswind effects and to insure reproducibility of results.

DISCUSSION

General

In designing a satisfactory lateral control system for the sailwing glider two major obstacles were encountered: the lack of wing structural members for the attachment of conventional ailerons which was previously mentioned, and the low dynamic pressures encountered over the operating speed range of the glider. In conventional hard wing sailplanes large flap-type ailerons with a wide range of deflection are frequently used to overcome this latter problem.

In the sailwing lateral control designs - with the exception of the spoiler configuration - the approach taken was to alter the lift distribution along the wing by varying the angle of attack of a part of the semispan as in conventional designs. The simplest method of accomplishing this appeared to be by deflecting a portion of the trailing edge cable. Since the cable tension is approximately 60 pounds it was anticipated that relatively large static control forces might be encountered.

Therefore, the first two configurations were exploratory attempts to determine how much cable deflection would be necessary for effective control at low speeds, and whether the necessary deflection could be obtained without encountering excessive static control forces and force gradients.

Tip Warping

Referring to Fig. 2 it is seen that because of the location of the wing tip hinge, deflection of the tip in either direction requires a lengthening of the trailing edge cable. This effect was expected, but it was felt that the lengthening could be accommodated by the bow in the cable without incurring excessive static control forces. When installation of this design on the glider was completed it was found that the static stick forces were prohibitively high at full deflection.

Since the static control force gradient was high, reducing the maximum deflection reduced the maximum control force considerably. However, for a wing tip deflection of only ± 20 degrees the maximum control force was still excessive, and the design was abandoned.

Trailing Edge Bridle

The static control forces and force gradients encountered in this configuration were also excessively high. By establishing the range of deflection from + 10 to − 3 degrees at $.5\,{}^{b}/_{2}$, the maximum stick force was reduced to a barely acceptable level.

With this design, as with the previous one, it was found that the dynamic stick forces were not appreciably greater than the static forces, due to the relatively small deflections involved and to the low dynamic pressure (3 to 4 lb./ft^2).

The results of five flight tests showed that the control effectiveness of this configuration was no better than the first.

As previously described, when the control stick is neutralized the trailing edge cables on both wings are restrained by the bridles from assuming their normal loaded curvature. When tension is applied to one bridle the trailing edge cable is pulled down and forward. Hence, the change in angle of attack which is effected at a given station is augmented by the increased camber which the sail assumes as the cable moves forward. As tension is applied to one bridle it is released in the other, and it moves upward and aft decreasing the angle of attack by the same combined effect. But with allowable deflections of + 10 and – 3 degrees the wing which is "spilling" lift is much less effective in generating a rolling moment than the one on which the left is being augmented. In addition, a change in angle of attack is generated over only .35 of the semispan. The result is a combination of too small a variation in α along too little of the span to produce satisfactory rolling moments.

Leading Edge Spoilers

Although lift spoilers of various types have been used as lateral control devices in a number of successful powered aircraft designs,

Ref. 3 states that their employment on hard wing sailplanes has not met with widespread success. This is due in part to a characteristic reduction in spoiler effectiveness at the low speeds and relatively high angles of attack associated with gliding flight. Ref. 4 reports that this effect is more pronounced at low spoiler deflections. Additional results contained in Ref. 4 indicate that an increasing time lag in control response may be encountered as the spoiler location is moved forward of the .7 c position.

The simple spoiler configuration described earlier was installed on the sailwing glider in an effort to avoid the excessive control forces previously encountered. It was hoped, despite the shortcomings mentioned above, that the degree of lateral control obtained would meet minimum requirements.

The static control forces and force gradients of this configuration were acceptably low as anticipated, but an unexpectedly severe deformation of the sail behind the spoiler was encountered in the initial tow tests. Fig. 11 shows this effect qualitatively. As the spoiler was deflected upward the low pressure region created immediately behind it caused the sail to balloon as shown. With further deflection this ballooning effect became more pronounced, and it persisted up to the maximum deflection of 60 degrees. But there was no apparent change in the contour of the lower surface of the wing. Because of this ballooning the effective projection of the spoiler above the upper surface contour was severely minimized throughout the deflection range. During the flight tests lateral control was found to be so weak that it was impossible to detect.

In a subsequent test with the spoiler mounted at a fixed deflection of 80 degrees the ballooning effect was not apparent; indicating that between 60 and 80 degrees the sail pulled away from the spoiler and returned approximately to its normal contour. It would seem then that the ballooning could be avoided by installing 90° deflection spoilers which would be extended and retracted into the wing at the spar.

To investigate this possibility three 90° deflection spoilers were attached to the aspect ratio 7 sailwing, and the rolling moment coefficients generated by each spoiler were determined at α = 10 and 20 degrees. No ballooning tendency was observed during these tests. Fig. 12 shows these rolling moments plotted versus C_s/C_w. At $\alpha = 10^{\circ}$ the moment due to the one inch spoiler was too small to be determined, but the other results conform in general to those for hard wings contained in Ref. 5. It is seen that the rolling moment coefficient, C_l', increases in a decaying manner with increasing angle of attack. This would seem to be in agreement with Ref. 4 which reports that C_l' is roughly proportional to C_L for spoilers located near the leading edge.

Although these results showed considerably more promise than did the previous configurations, the installation of this type of spoiler on the glider would require cutting long slots in the sail. It was felt that this would compromise its strength and alter its camber characteristics unfavorably, and the design was set aside.

Modified Flap-type Ailerons

The measured rolling moment characteristics obtained with this design incorporated in the aspect ratio 7 sailwing are shown in Fig. 13. During the tests it was found that the airspeed could be read to within $\pm$ .5 mph with accuracy, but the effect of an error of .5 mph on the resultant value of C_ℓ' is negligibly small. And although the values of C_ℓ' were found to be very sensitive to crosswind effects, this source of error was reduced somewhat by repeating each test under different wind conditions whenever possible and averaging the results. Thus, the rolling characteristics shown in Fig. 13 are felt to be a reasonably accurate representation of the true characteristics of the configuration.

Fig. 13 shows C_ℓ' to be a linear function of aileron deflection above $\delta_a = \pm 5^\circ$, and throughout the α range of the tests. Some of the curves indicate a slight non-linearity below $\delta_a = \pm 5^\circ$ which is seen to be more pronounced at the higher angles of attack. Whether this is a true characteristic of the design or a random error in the data could not be determined, because the test setup was not sufficiently sensitive to aileron deflections below five degrees to give consistent results. There was no measurable effect on the rolling moment characteristics resulting from the treatment of the sail to reduce its porosity.

The isolated effects of positive and negative aileron deflections are shown in Figs. 14 and 15 for α = 10 and 20 degrees respectively. These curves show that there is no appreciable effect of angle of attack on the

proportional contributions of the upgoing and downgoing ailerons. For both angles of attack the down aileron is roughly three times as effective in producing a rolling moment as the up aileron over the range of deflections. This general trend is also characteristic of many hard ailerons.

No particular significance could be attached to the fact that the slopes of the individual aileron curves are slightly lower than those of the combined $\pm$ deflections. Due to the lack of sensitivity of the test set-up to small rolling moments the moment data for the individual ailerons had considerably more scatter. This was particularly true for the negative deflections (up aileron) where the moments were relatively small.

To determine the roll rate produced by the measured moments the non-dimensional rolling parameter, $\frac{pb}{2V}$, was used. This parameter, which is actually the helix angle described by the wing tip during a roll, was calculated using the relationship,

$$\frac{pb}{2V} = \frac{C_{\ell_{\delta a}}}{C_{\ell_p}} \delta a \qquad (1.)$$

The error in this calculation due to the apparent non-linearity of $C_{\ell_{\delta a}}$ below five degrees is small. The value of C_{ℓ_p} was taken as .48 from the curves presented in Ref. 6 of C_{ℓ_p} versus aspect ratio and taper ratio for hard wings. The calculated values of $\frac{pb}{2V}$ for the maximum aileron deflection of $\pm 35^{\circ}$, and values of $\frac{pb}{2V}$ per degree of aileron deflection are tabulated below.

Rolling Moment Parameters Obtained
From Tests of Aspect Ratio 7 Sailwing

α^{o}	$C_{\ell_{\delta a}}$	$\frac{pb}{2V}$	$\frac{pb}{2V}/\delta a^{o}$
0	-.0024	.175	.0050
5	-.0018	.131	.0038
10	-.0017	.124	.0035
15	-.0015	.109	.0031
20	-.0014	.102	.0029
25	-.0012	.088	.0025

For comparison of these values with a typical light powered aircraft, the Navion has a $\frac{pb}{2V}$ of approximately .10 at maximum aileron deflection or .002 per degree of aileron deflection.

The decrease in $C_{\ell_{\delta a}}$ and consequently in $\frac{pb}{2V}$ with increasing α cannot be conclusively explained with the limited data at hand. It is possible that due to the greater camber of the sail which occurs with increasing α, the increment in α obtained per degree of aileron deflection, $\frac{\Delta\alpha}{\delta a}$, is reduced. It is characteristic of sailwings, as reported in Ref. 2, that the trailing edge cable deflects forward and upward as α is increased. The forward motion of the cable results in a reduction in aileron area which would account for the decrease in $\frac{\Delta\alpha}{\delta a}$, and hence $C_{\ell_{\delta a}}$, with increasing α.

The nature of the decrease in aileron effectiveness is shown in Fig. 16 in which $\frac{pb}{2V}/\delta a$ is plotted versus α. The relatively large loss in effectiveness from $\alpha = 0$ to 5 degrees could be associated with a greater rate of cable deflection as the airfoil goes from a symmetrical section at $\alpha = 0$ to some positive camber at $\alpha = 5^{\circ}$, with decreasing rate of deflection as α increases beyond five degrees. This would tend to add substance to the above argument, but proof of this interrelation between cable deflection and rolling effectiveness requires a more exact quantitative knowledge of sailwing behavior than has been obtained to date.

With the rolling moment results of the aspect ratio 7 sailwing it is possible to estimate the rolling performance of the sailwing glider for this aileron configuration using the method of Ref. 7 and the curves of $\frac{C_{\ell_{\delta a}}}{\tau}$ and C_{ℓ_p} of Ref. 6. Using the previously determined value of $\frac{pb}{2V}/\delta a$ for $\alpha = 10$ as a representative value for the smaller wing the equation,

$$\frac{pb}{2V} = \frac{C_{\ell_{\delta a}}}{\tau} \quad \frac{\tau\,\delta a\,K}{114.6\,C_{\ell_p}}, \qquad (2.)$$

was solved for $\frac{C_{\ell_{\delta a}}}{\tau} = .271$. The curve of $\frac{C_{\ell_{\delta a}}}{\tau}$ versus extent of aileron of Ref. 6 was then utilized to determine the effective extent of the sailwing ailerons. This value was found to be $.5\,{}^{b}/_{2}$.

The installation of this aileron configuration on the sailwing glider would result in the same effective extent of aileron with a very

small error incurred due to slight variations in the curvatures of the trailing edge cables of the two wings. However, the aileron chord to wing chord ratio would change from .27 to .31 for the larger aspect ratio wing. Using these numbers and the geometric characteristics of the aspect ratio 11 wing the following values of $\frac{C_{\ell_{\delta a}}}{\tau}$, τ, K and C_{ℓ_p} were taken from the curves of Ref. 6 and 7:

$$C_{\ell_{\delta a}}/\tau = -.30$$

$$\tau = .48$$

$$K = .8$$

$$C_{\ell_p} = -.54$$

Substituting these values back into equation (2.) gave a value of $\frac{pb}{2V}/\delta a = .0037$ for the sailwing glider at $\alpha = 10^\circ$. This procedure was repeated for the remaining angles of attack, and for comparison of the two wings a curve of $\frac{pb}{2V}/\delta a$ versus α for the aspect ratio 11 sailwing was added to Fig. 15.

The rate of roll which could be obtained from the sailwing glider provides a measure of the effectiveness of this lateral control configuration. Since the rate of roll for a given value of $\frac{pb}{2V}$ varies inversely with wing span and directly with velocity, the sailwing glider with its 31 foot span will have a lower rate of roll which will decrease further with decreasing speed. In this respect the lowest rate of roll would be available during the landing phase and might become critical.

Based on flight test experience the glider landing configuration is estimated to be : $V = 40$ mph and $\alpha = 20^{\circ}$. Under these conditions the predicted rate of roll was calculated to be 22 degrees per second for full aileron deflection and 12.6 degrees per second for $\pm 20^{\circ}$ of deflection. The rate of roll for $\delta a = \pm 20^{\circ}$ is somewhat low for satisfactory lateral control in correcting for asymmetrical vertical gust loads. Therefore, the full deflection of $\pm$ 35 degrees should be available to the pilot.

These predictions of rolling performance have been made on a rather elementary basis. Many factors which can affect the rate of roll adversely have been neglected, because they cannot be predicted with any degree of accuracy without extensive tests, which it was felt would delay the development of the sailwing glider unnecessarily. For the most part these effects on rolling performance are of second order magnitude, but an adverse combination of them could reduce the predicted rate of roll substantially. Some of these factors are wing twisting, dihedral effect and adverse yaw characteristics, radius of gyration in roll, and roll damping of the glider components other than the wing.

It must be considered also that a satisfactory rate of roll does not of itself describe adequate lateral control. The other vital factor is the time lag in control response. It was not within the scope of this investigation to determine the control response of this design. However, the similarity in characteristics between this design and conventional hard ailerons in other respects would seem to indicate a similarity in control

response. For most simple, hard aileron designs the time lag in control response is characteristically low, and this is hoped to be the case for the sailwing glider.

Another lateral control feature which was not investigated was the nature of the control forces to be expected for the sailwing glider installation. Experience with the aspect ratio 7 wing indicated that obtaining low static control forces would be primarily a matter of providing suitable bearings for the aileron arms. With the proper bearing design the static forces could be reduced significantly. It could not be expected that these forces would be reduced to the level of conventional ailerons because of the additional forces and moments transmitted to the bearings from the trailing edge cable.

With the static forces reduced to an acceptable level the dynamic forces to be encountered in the low speed region of the glider are not expected to be critically high. The overall result is thus anticipated to be control force characteristics which will be somewhat greater in magnitude than those encountered with hard ailerons, but not so great as to prove unsatisfactory.

CONCLUSIONS AND RECOMMENDATIONS

1. Lateral control designs for sailwings which tend to increase the tension in the trailing edge cable during control deflections are characterized by unacceptably high static control forces.

2. The leading edge spoiler installation on the sailwing glider produced a ballooning effect in the sail, resulting in unacceptably low control effectiveness.

3. The modified flap-type aileron configuration was the most promising of the designs tested in all respects, and it is recommended that it be installed in the sailwing glider.

REFERENCES

1. Sweeney, T. E.: A Disclosure of the Sailwing Concept. Department of Aeronautical Engineering, Princeton University, Unnumbered Report, May 1961.

2. Sweeney, T. E.: Exploratory Sailwing Research at Princeton. Department of Aeronautical Engineering, Princeton University, Report No. 578, December 1961.

3. Kukuski, John: Theory and Technique of Soaring; 1952, Sir Isaac Pitman & Sons, Ltd., London.

4. Toll, Thomas A.: Summary of Lateral-Control Research by Langley Research Department. NACA TN No. 1245, 1947.

5. Shortal, J. A.: Effect of Retractable-Spoiler Location on Rolling- and Yawing-Moment Coefficients. NACA TN No. 499, 1934.

6. Pearson, Henry A. and Jones, Robert T.: Theoretical Stability and Control Characteristics of Wings with Various Amounts of Taper and Twist. NACA Report No. 635, 1938.

7. Perkins, C. D. and Hage, R. E.: Airplane Performance, Stability and Control; 1949, 2nd ed., John Wiley and Sons, Inc., New York.

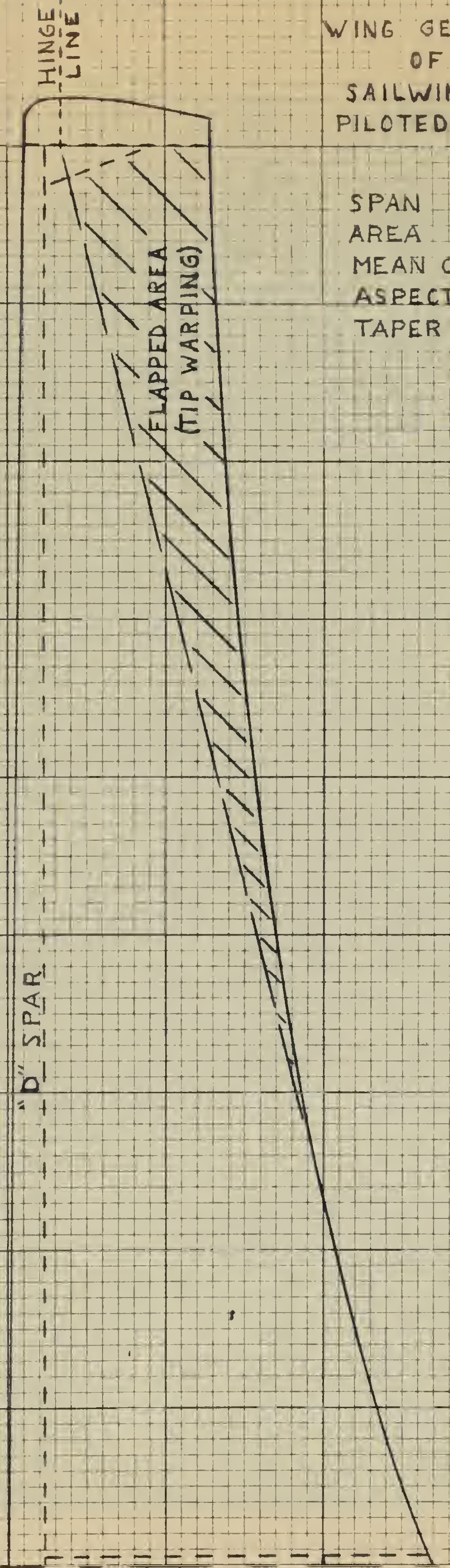
FIG. 1

GENERAL VIEW OF SAILWING GLIDER

WING GEOMETRY
OF
SAILWING II
PILOTED GLIDER

FIG. 2

SPAN	=	31ft.
AREA	=	87ft.^{2}
MEAN CHORD	=	2.9ft.
ASPECT RATIO	=	11
TAPER RATIO	=	.44



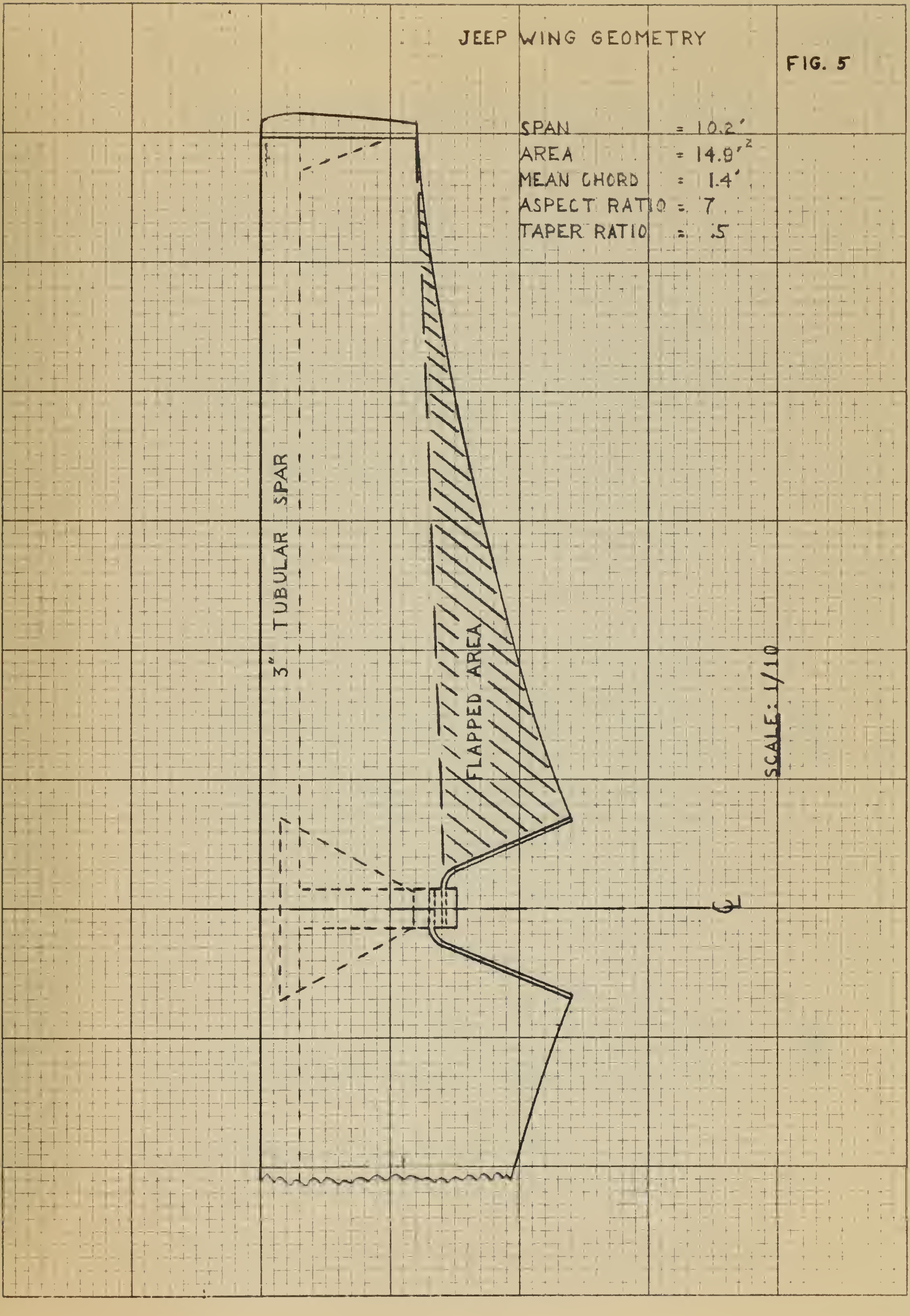
SCALE: 1/20

FIG. 3

ASPECT RATIO 7 SAILWING INSTALLATION

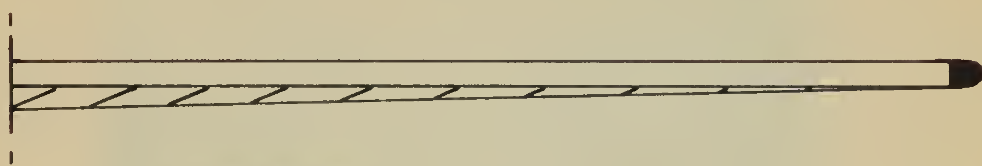
FIG. 4

DETAIL OF ASPECT RATIO 7 SAILWING MOUNTING

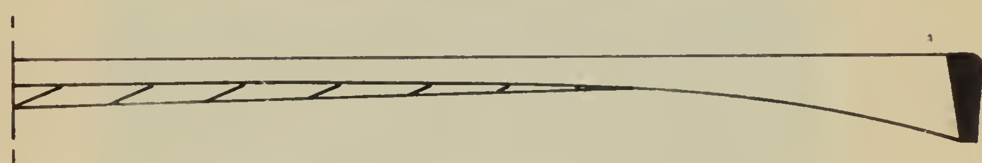

JEEP WING GEOMETRY
FIG. 5
SPAN = 10.2′
AREA = 14.9′²
MEAN CHORD = 1.4′
ASPECT RATIO = 7
TAPER RATIO = .5
3″ TUBULAR SPAR
FLAPPED AREA
SCALE: 1/10

TRAILING EDGE CABLE DEFLECTIONS DURING TIP WARPING OF ASPECT RATIO 11 SAILWING

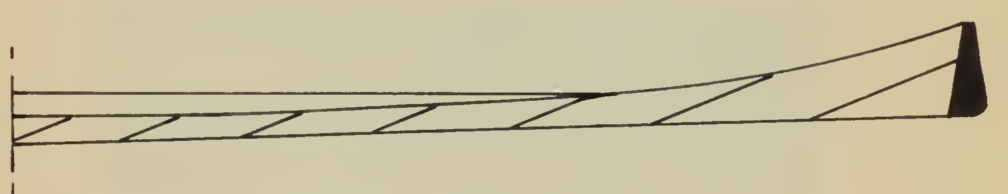
Note: Chordwise view from rear
Lower surface is shaded



a. Zero deflection



b. Maximum positive deflection



c. Maximum negative deflection

TRAILING EDGE BRIDLE CONFIGURATION

a. DETAIL OF BRIDLE ARRANGEMENT

b. TRAILING EDGE CABLE AT FULL DEFLECTION

c. TRAILING EDGE CABLE AT ZERO DEFLECTION

FIG. 8

a. NO DEFLECTION

b. FULL DEFLECTION

SPANWISE VIEWS OF BRIDLE INFLUENCE ON TRAILING EDGE CABLE AT 25 MPH

INFLUENCE OF FLAP-TYPE AILERON DEFLECTION

ON CAMBER DISTRIBUTION OF

ASPECT RATIO 7 SAILWING

AT 25 MPH

FIG. 9

a. $\alpha = -15^\circ$, $\delta_a = +35^\circ$

b. $\alpha = -15^\circ$, $\delta_a = -35^\circ$

FIG. 10

INFLUENCE OF FLAP-TYPE AILERON DEFLECTION
ON TRAILING EDGE CABLE OF
ASPECT RATIO 7 SAILWING
AT 30 MPH
$\alpha = +15^\circ$

a. $\delta_a = 0$

b. $\delta_a = -35^\circ$

c. $\delta_a = +35^\circ$

BALLOONING EFFECT DUE TO LEADING EDGE SPOILERS ON ASPECT RATIO 11 SAILWING

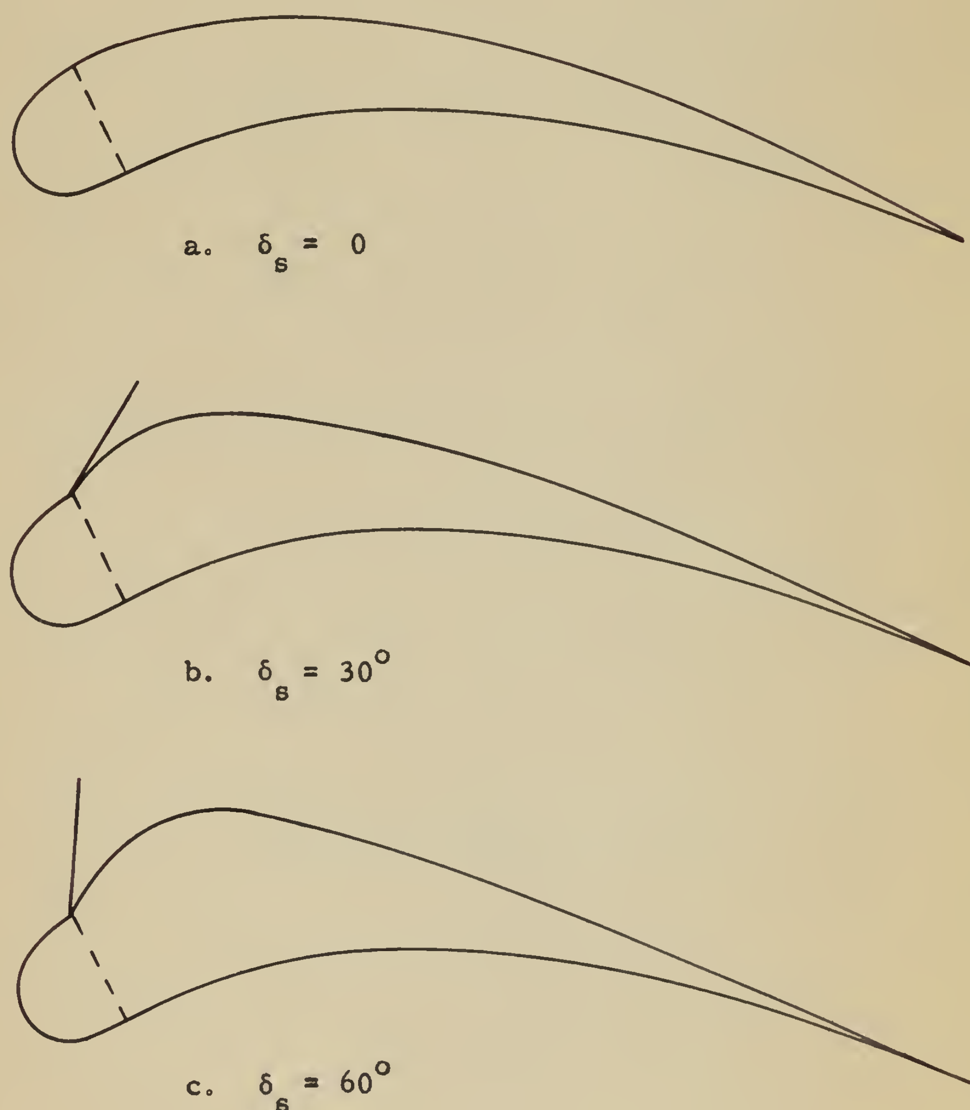
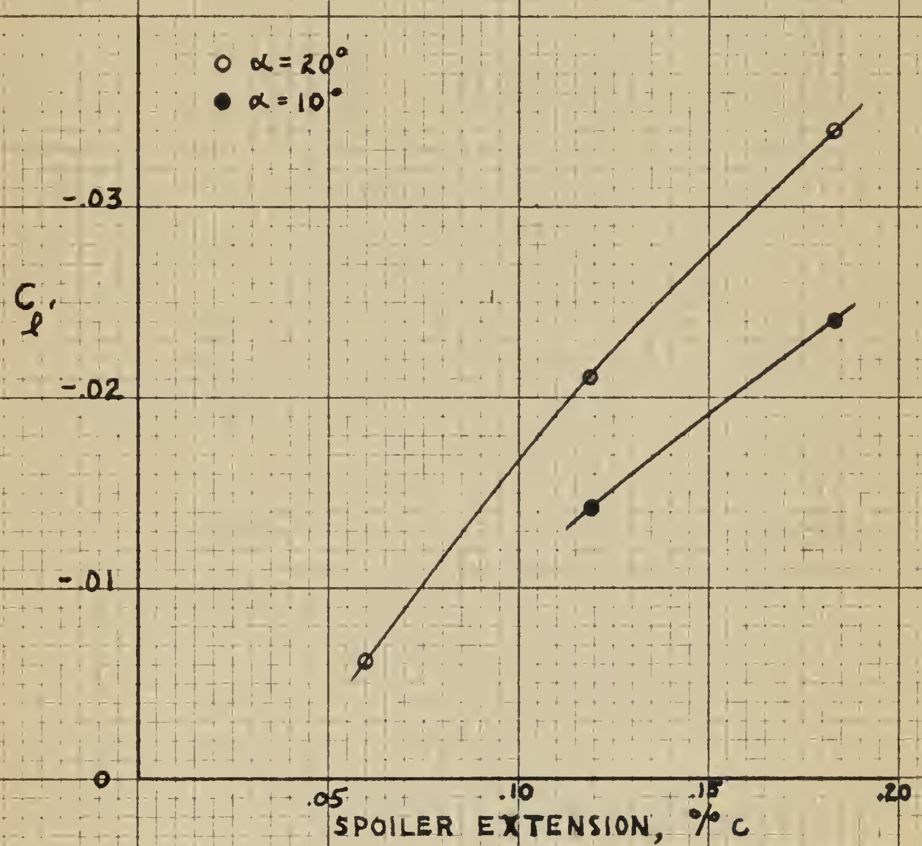


FIG. 12

ROLLING MOMENT CHARACTERISTICS
OF THREE 90° SPOILERS
LOCATED AT .09c
ON ASPECT RATIO 7 SAILWING
AND
EXTENDING FROM .35 b/2 TO .95 b/2

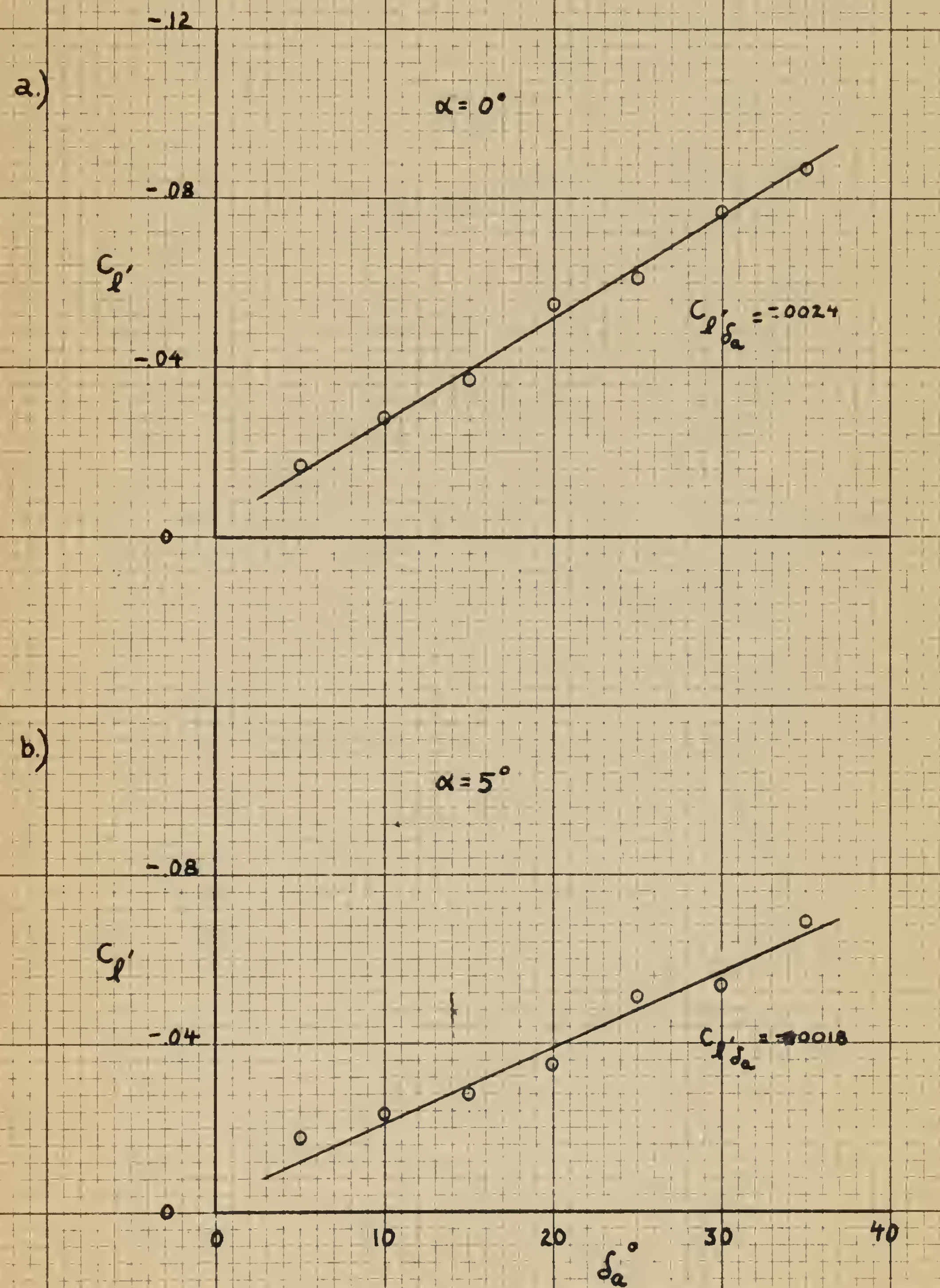


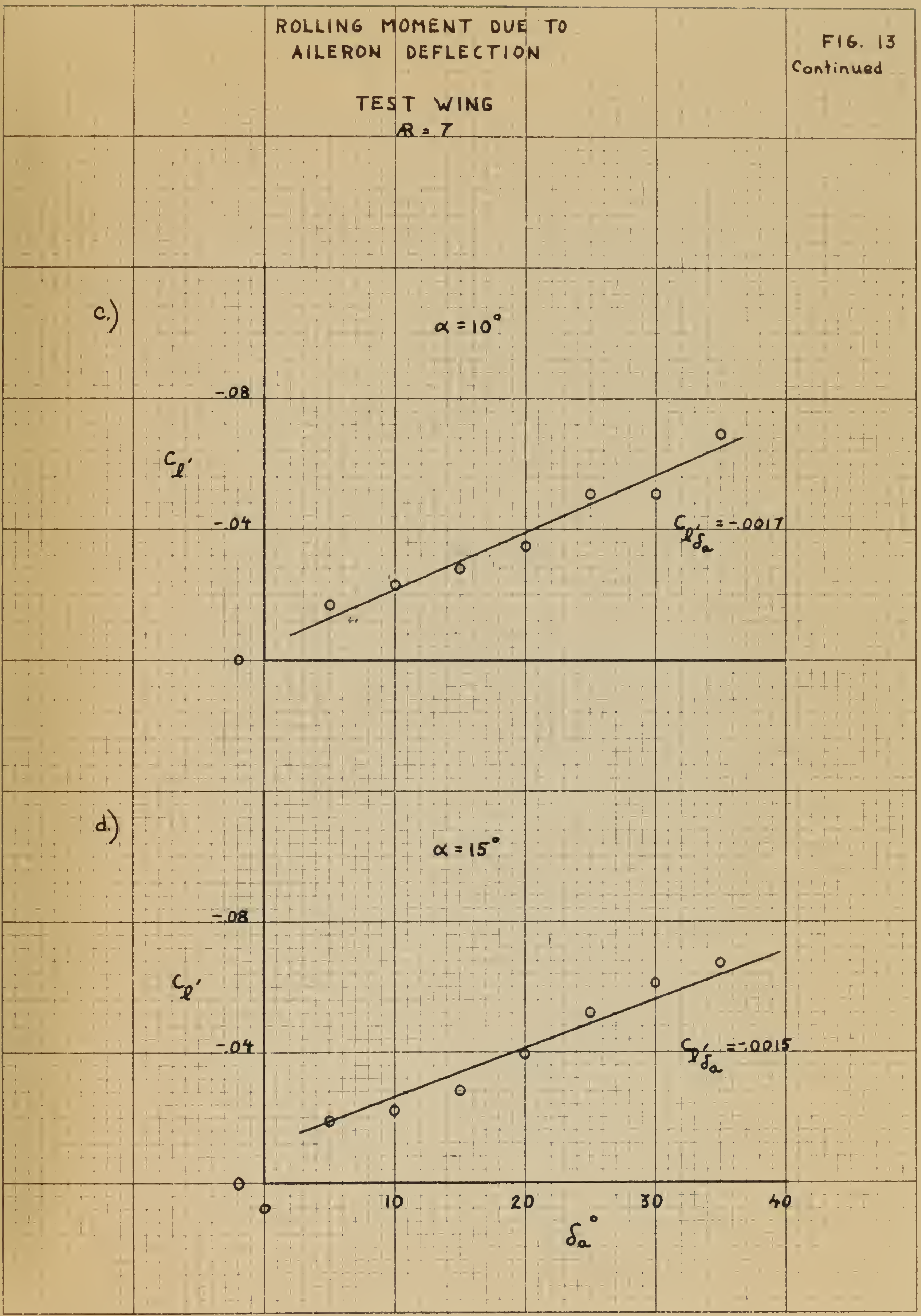
ROLLING MOMENT DUE TO AILERON DEFLECTION

TEST WING

Æ = 7

FIG. 13





ROLLING MOMENT DUE TO AILERON DEFLECTION
TEST WING
AR = 7
FIG. 13
Continued
c.)
α = 10°
-.08
-.04
0
C_l'
C_lδa' = -.0017
d.)
α = 15°
-.08
-.04
0
C_l'
C_lδa' = -.0015
0
10
20
30
40
δa°

ROLLING MOMENT DUE TO AILERON DEFLECTION

TEST WING
Æ = 7

FIG. 13
Concluded

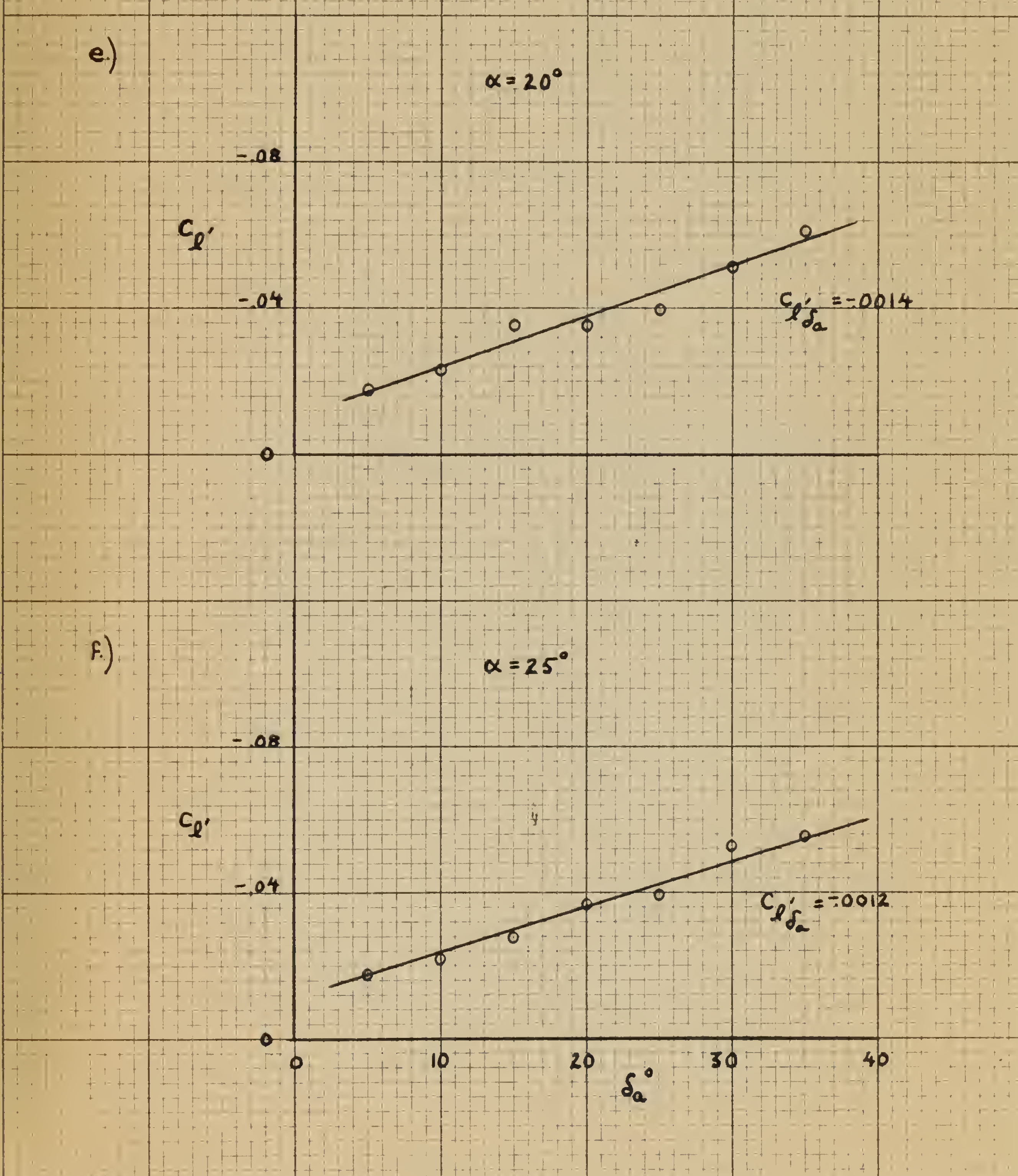


FIG. 14

ROLLING MOMENTS DUE TO INDEPENDENT AILERON DEFLECTIONS

$\alpha = 10^\circ$

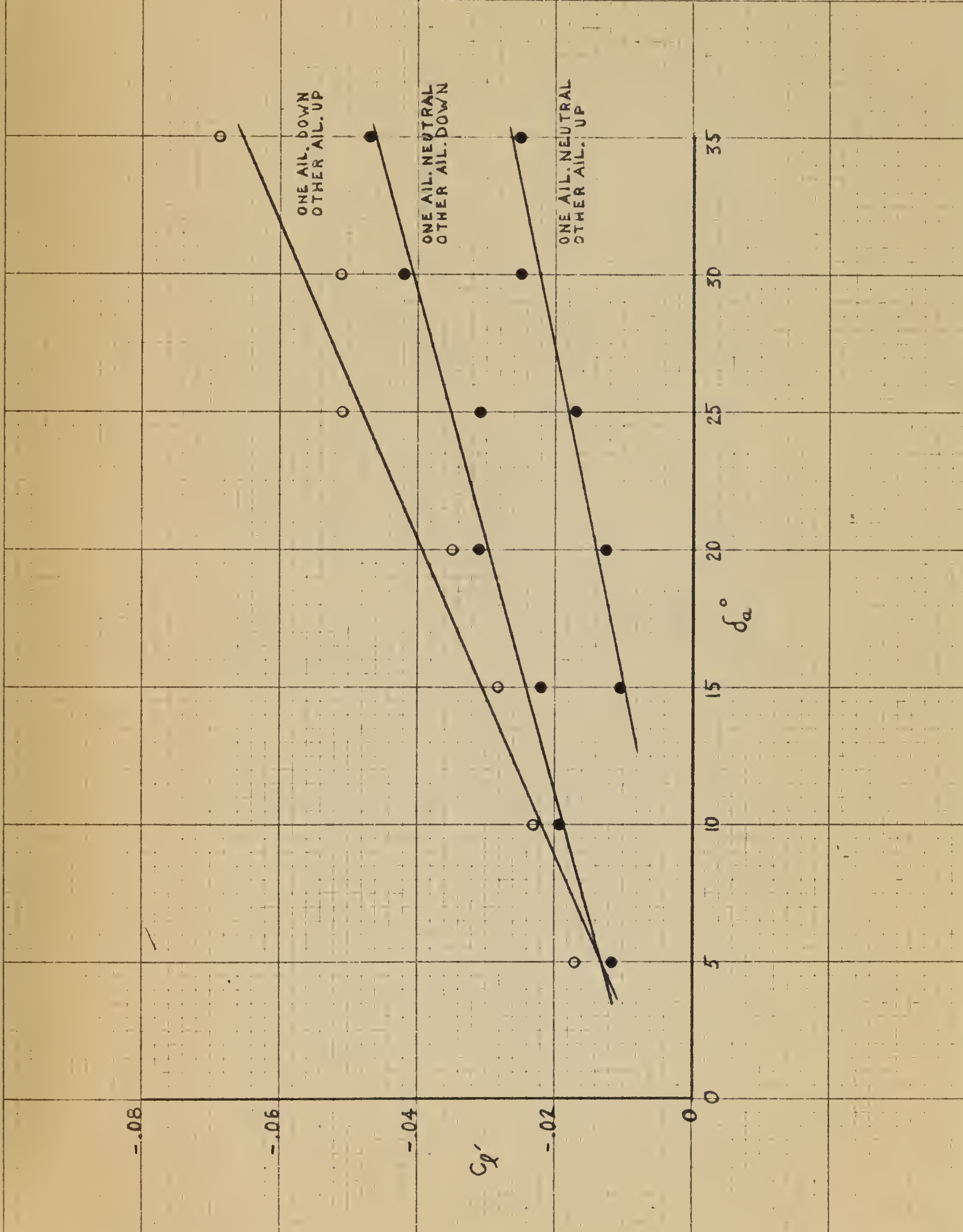


FIG. 15

ROLLING MOMENTS DUE TO INDEPENDENT AILERON DEFLECTIONS

$\alpha = 20°$

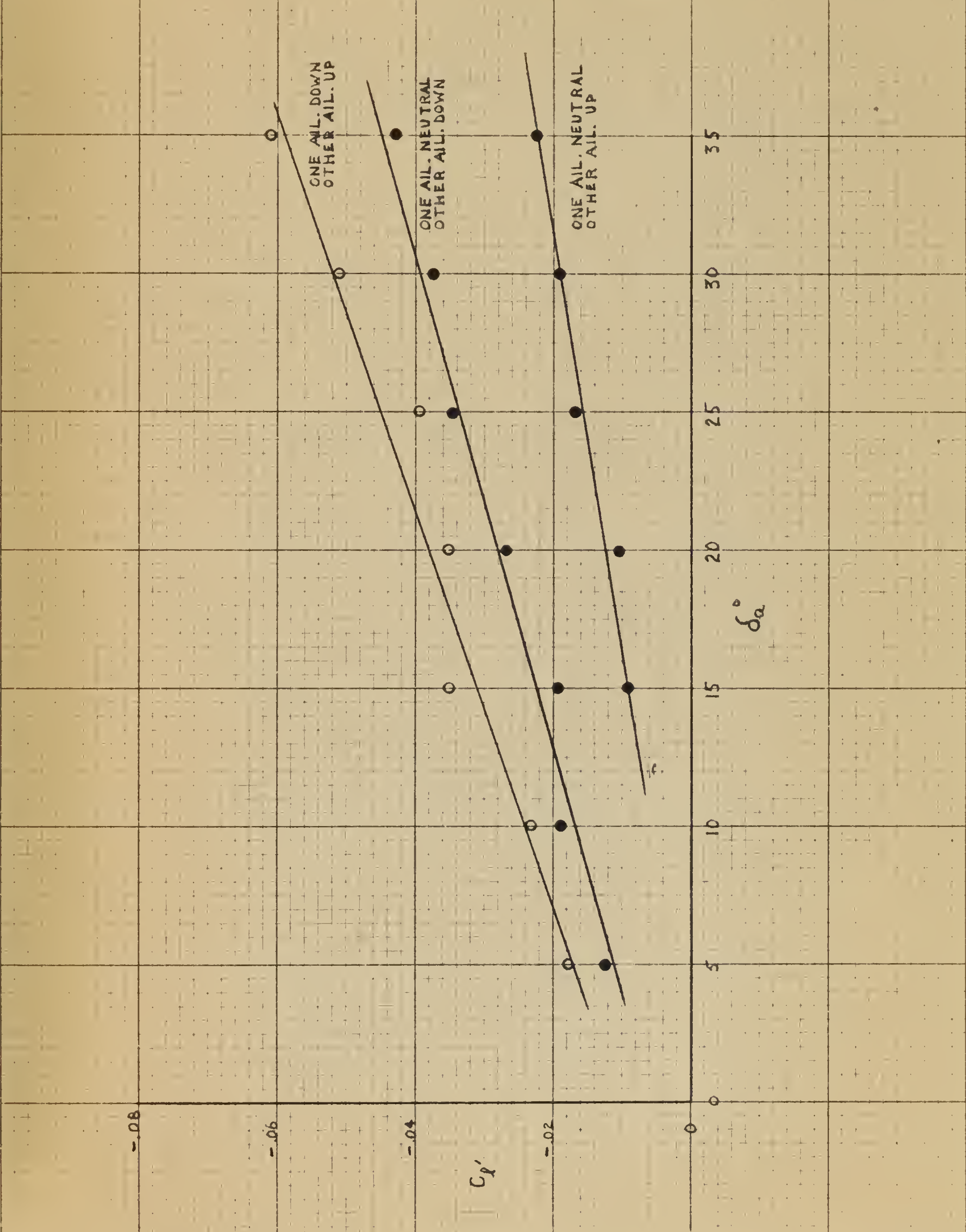
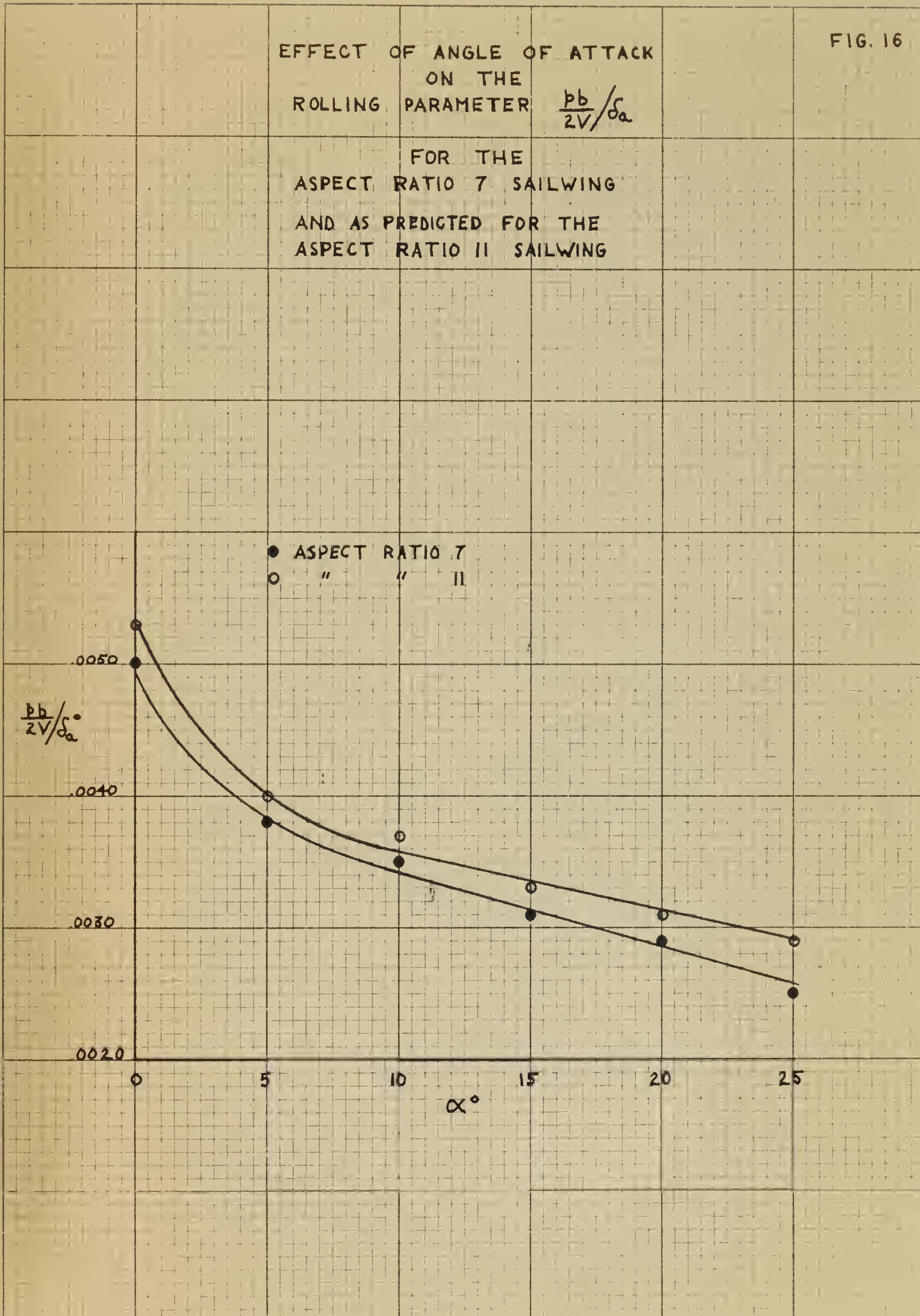


FIG. 16



EFFECT OF ANGLE OF ATTACK ON THE ROLLING PARAMETER $\frac{pb}{2V}/\delta_a$
FOR THE ASPECT RATIO 7 SAILWING
AND AS PREDICTED FOR THE ASPECT RATIO 11 SAILWING
● ASPECT RATIO 7
○ " " 11
.0050
$\frac{pb}{2V}/\delta_a^\circ$
.0040
.0030
.0020
0
5
10
15
20
25
α°